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Simulation Game for Intelligent Production Logistics – The PuLL® Learning Factory

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Abstract

The PuLL® Competence Centre operates a learning factory for application-related research and education in the area of Lean Production / Lean Logistics for students and companies with the didactic approach of simulation games. The Competence Centre developed a new learning factory for "intelligent production logistics". A new simulation game was developed with the learning focus on internal material flow, intelligently combined with Industry 4.0 components. The goal is to teach the adequate application of Industry 4.0 technology in production logistics. A survey is going to evaluate the specific problems of logistics planning in the field of "intelligent production logistics".

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Keywords: learning factory; simulation game; intelligent production logistics; Industry 4.0; Lean Production

1. From a Lean learning factory to a learning factory for intelligent production logistics

The PuLL® Competence Centre, as a department of the University of Applied Sciences in Landshut, opened its Lean learning factory in 2010. It was designed to mainly teach and train methods as well as principles of Lean Production and Lean Logistics. Section 2.2 describes the content of this Lean learning factory in detail. The necessity for a new learning factory concept is presented in section 3, the new concept itself in section 4. As a result of the explained demand for a new learning factory concept, section 5 describes a newly developed simulation game for intelligent production logistics.

2. Lean learning factory

The Lean learning factory (see figure 1) is classified according to the morphology of Abele et. al. in this section [1]. It comprises a physical assembly line which is operated on 200 m² shop floor. The main purpose is the education of students from bachelor and master studies in Industrial Engineering and Management. Secondary purposes are application-related research projects and trainings. In this context, the learning factory acts as a research enabler and use-case scenario, focusing on production and Lean Management, e.g. for real-time customer order management. In the latter, trainings are conducted for employees of all

Figure 1: The Lean learning factory

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hierarchies of production and logistics companies, ranging from small companies to car manufactures like the BMW Group. Thus the group constellation varies from homogenous student groups to heterogeneous groups of employees with about eight to 15 participants per training. In total, approximately 200 people participate in the typically one to two day trainings per year. With instructed onsite learning, the trainer acts as a moderator and coach in the standardized trainings, which alternate theoretical and practical parts.

2.1. Infrastructure and equipment

The heart of this Lean learning factory is a manually operated assembly line for trolleys. The line and the product are a copy of an existing set-up in a production company. After each training, the trolleys are disassembled for re-use. The supply of materials to the seven assembly stations is organized with a synchronized tugger train and a supermarket concept. On the subject of the manufacturing organization, the production layout of this assembly line is changeable from job shop to a U-shaped flow production, depending on the purpose of the respective training. Hence the changeability dimensions of this Lean learning factory include the layout and logistics as well as the production lot sizes, affecting the work system levels of the single work place, the work system and the factory.

One special feature of this learning factory is the installation of a real-time location system. This system is used to create a layout-based order steering software (LOS1), which was developed in an application-related research project from 2011 to 2014. This technology enables a continuous tracking of customer orders during the manufacturing process on the basis of real-time data [2].

2.2. Didactics and learning content

The learning content has two major parts, firstly the Lean principles and secondly the analogy of a logistics transmission. As the didactic approach of this Lean learning factory, a simulation game is used which emphasizes methodological competencies in Lean Production and Lean Logistics. The learning scenario strategy is composed of demonstration and a closed scenario. Apart from the eight systematic first principles of Lean (tact, flow, pull, standard, stability, synchronization, integration, perfection) [3], the formal principles listed in table 1 is the first main learning content of this Lean learning factory [4].

Table 1: Formal first principles of Lean

Andon	Worker triangle
U-shaped assembly line	Multi-station operation Andon
One-piece-flow	Poka Yoke
Nurse-surgeon principle	Synchronized tugger train
Two-handed working	Production synchronized to customer tact
Single-point pick-up	Supermarket near assembly line
Kanban	Heijunka

The second main learning content of this facility is taught via the analogy of a “logistics transmission”. In this learning scenario, the logistics transmission has three different gear-wheels which describe three different logistics cycles of material and information flow (see figure 2). This analogy of a logistics transmission focusses on the learning content of the cycle time of material and information flow of the different gear-wheels as well as the size of carriers in all three gear-wheels. This shows an integrated system from the single work station to the suppliers. As it is in the transmission of a car, the logistics transmission has several gear-wheels with therefore different speed of rotation, in other words different cycle times.

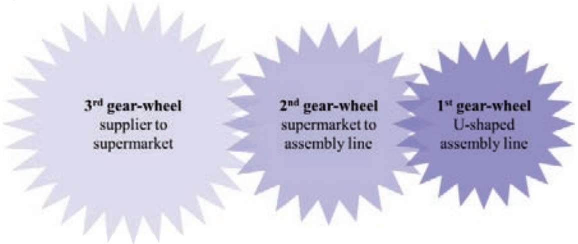

Figure 2: Example of the gear-wheels of a logistics transmission

The highest, in this case the third gear-wheel, represents the delivery of parts from a hypothetical supplier to the supermarket of the factory, organized with Kanban folders attached to the pallets and a supplier Kanban board. This gear-wheel operates at a comparably slow cycle time of e.g. one delivery per week in the form of complete pallets / large load carriers. Followed by that, the second gear-wheel symbolises the supply of parts from the supermarket to the assembly line of the factory with a synchronized tugger train. The cycle time is already much higher than in the 3rd gear-wheel with one tugger train run every 30 minutes and with small load carriers. The information flow is organized with Kanban cards attached to the small load carriers at the assembly stations. The logistician picks up empty carriers and replaces them in the next run. Finally, the first gear-wheel is the flow of customer orders, respectively the final product, within the U-shaped assembly line. The cycle of this gear-wheel is again higher than in the others, in this case one product is assembled every 75 seconds, according to the customer tact.

The main didactic training tool in the Lean learning factory is the simulation game “From Job Shop Production to One-Piece-Flow”. The participants have different roles (e.g.

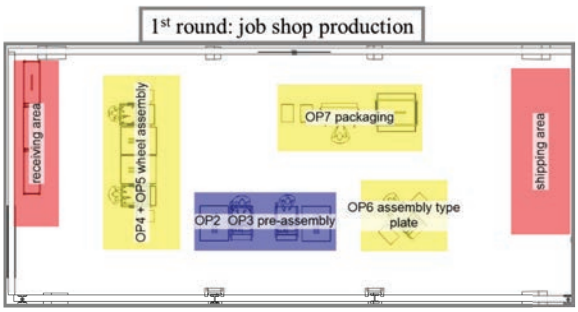

Figure 3: Changeability of production layout – 1st simulation round

logistics, foreman and worker) and produce the trolleys in the first round in a push-oriented production system with lot sizes. The layout of the learning factory is according to a job shop production (see figure 3). In a first debriefing session, the trainer analyses, together with the participants, the situation in this production system with the help of key performance indicators (KPI) as hard facts as well as with soft facts.

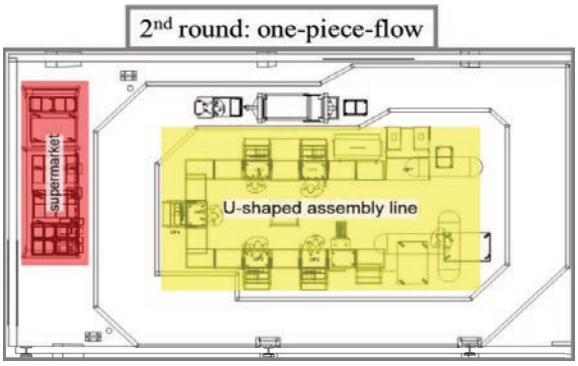

Figure 4: Changeability of production layout – 2nd simulation round

The simulation game is designed in a way, which makes the lack of transparency in the production system and the use of lot sizes the main occurring problems. As a special feature, the real-time location system tracks the logistician in order to visualize the chaotic travel paths. Based on that assessment, the production layout of the learning factory changed to a U-shaped and pull oriented flow production (see Figure 4). The participants then run this production system with the same customer orders as in the first round. They then experience the tremendous difference between the two set-ups of the Lean learning factory. In a second debriefing session, the KPIs from the two production scenarios are compared and discussed with the participants.

3. Necessity for new learning factory concept

When it comes to modern and holistic production systems, the principles and methods of Lean Production are seen as best-practice, especially for high-variant series production [5, 6]. Therefore, the Lean learning factory covered these important topics in research, teaching and training.

Nevertheless, the ongoing discussion about Industry 4.0 raises questions, e.g. about if and how Lean and Industry 4.0 can be combined? Industry 4.0 is the exhaustive penetration of the production through information technologies and the use of machine intelligence for the short term planning, optimization and steering of processes [7]. Industry 4.0 hereby describes a new way of an economic production, which is characterized by a continuous digitalization and a stronger in-plant and interplant cross-linking. This fourth industrial revolution has an impact on all dimensions of a company, like technology, organization, people and business models [8]. Production companies face the challenge that higher production flexibility is required while the number of production variants is increasing, causing higher complexity in production [7, 9]. When it comes to production logistics, it is indicated that processes designed according to Lean principles can be further optimized through the use of Industry 4.0 technology and cope with higher complexity [10].

This opens new possibilities for additional process improvements e.g. in the dimension organization through Industry 4.0 technologies as an enabler. An example for the interaction of the dimensions is the so called injection principle for internal material flow. This principle is based on the technology of an autonomous robotic carrier, which injects material from above to the shop floor in the form of small load carriers (see Figure 5). The advantages of this concept are e.g. the reduced space for material storage in production areas, a basically unlimited number of production variants possible, multi machine operation and reduced space for machines as well as reduced inventory on the shop floor. This means that with the injection principle, an already with Lean principles planned internal material flow can be further optimized through Industry 4.0 technologies [10]. Further examples of problems which cannot be faced by alternative approaches are:

- Layout based order steering with the use of a real time location system (RTLS) [2]
- Tracking of tugger trains and tugger train trailers for predictive maintenance using a RTLS
- Continuous improvement of the material flow using real time data generated by a RTLS tracking logistics equipment

Figure 5: Learning factory for intelligent production logistics (IPL)

Since these topics is rarely explored and only a few use cases exist so far, it is necessary to intensify research, teaching and training in this matter to support companies in achieving further progress.

For this reason, it is required to extend the Lean learning factory with Industry 4.0 characteristics in order to address these newly raised questions. As logistics, being a cross-departmental function, intelligently integrates processes and supply chains, it plays an important role on the way to Industry 4.0 [11–13]. With their responsibility for planning and improving (production) logistics processes, logistics planners are therefore the key to unlock the potential lying in the combination of Lean principles and Industry 4.0 technology. Consequently, they should be a focus group of teachings and trainings in a new learning factory concept including a new simulation game.

4. Learning factory for intelligent production logistics (IPL)

Due to the explained need for an extended learning factory concept in section 3, the PuLL® Competence Centre developed a completely new conception of a 900 m² physical learning factory for intelligent production logistics.

Production logistics is hereby defined as "(…) the design, planning and steering of all sub-processes of the production process – material and information processes – with the application of the logistical principles of a holistic approach, customer orientation and flow orientation." [14]

In this context, intelligent production logistics is defined as the introduction and application of Industry 4.0 technology in production logistics with the target of further process improvements. With their novelty and intelligently combined use, these technologies extend the area of production logistics through general Industry 4.0 characteristics. Such characteristics are e.g. the real-time availability of production and logistics data, decentralized decision structures as well as the interlinking of people, products and logistics equipment through information technologies [7, 9, 15–17].

The general aspects of the Lean learning factory as mentioned in section 2 are still applicable in the new learning factory. The major differences are in the size, infrastructure and equipment and the extended scope of the content.

4.1. Infrastructure, equipment and Industry 4.0 technology

This learning factory has the goal to illustrate the complete value stream of a production company with the use of state-of-the-art equipment and infrastructure. Therefore, all necessary areas exist, such as receiving and shipping area, picking area as well as production and assembly areas (see figure 5 and 6). Following is a list of the respective equipment:

- station for turning and lifting of pallets,
- trolleys, trolley-hub and trolley-store for transportation of large standard stillage,
- pallet storage and super market,
- order picking system for small part containers,

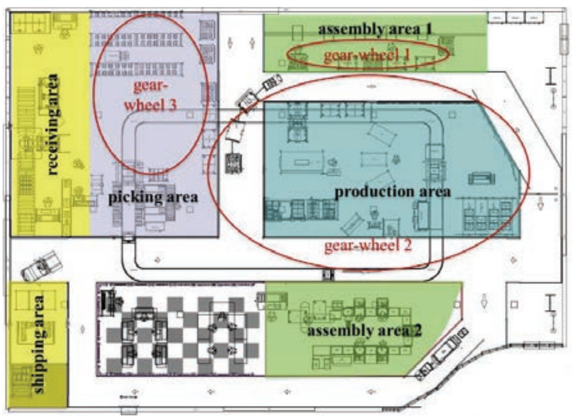

Figure 6: Logistics transmission and layout of new learning factory

- tugger trains with different tugger train trailers,
- super market rack system and Kanban board for pre-assembly area,
- learning cells.

The assembly line for trolleys, already explained in section 2, is used as one of two assembly lines in the new learning factory. In addition, a Lean shop is integrated for cardboard-engineering workshops. With reference to Industry 4.0 technology for intelligent production logistics, the following equipment and infrastructure is installed in the learning factory:

- control centre for production with real-time location system and PPS software for Lean,
- tracking of tugger trains with real-time location system for continuous optimization of material flow,
- automated guided vehicle (AGV),
- automated loading and unloading of the tugger train trailers,
- "Servus" intralogistics system as an autonomous transport robot including automated small parts storage and order picking [18].

The following sections explain how the infrastructure and equipment is used in teaching and training.

4.2. Didactics and learning content

Additionally to the content of the Lean learning factory and the simulation game "From Job Shop Production to One-Piece-Flow", a new simulation game as the main didactic approach was developed. This new simulation game extends the scope of trainings at the PuLL® Competence Centre and is explained in detail in section 5. The framework for the content of this learning factory still consists of the Lean principles and methods including the logistics transmission as explained in section 2.2. In the Lean learning factory, only the two following topics were addressed in the logistics transmission:

1. Cycle time of material and information flow
   In every gear-wheel of the logistics transmission, material and information move at a different timed sequence. The closer a gear-wheel operates to the final assembly line, the shorter the cycle time gets (see figure 6).
2. Size of carriers
   The size of carriers is directly related to the cycle time. This means, the smaller the used carrier in a gear-wheel is, the shorter the cycle time has to be in order to supply sufficient material.

In contrast to the Lean learning factory concept, there are two major differences in the learning factory for intelligent production logistics. First, the changeability of the layout is reduced to the individual areas. This means that the layout of certain areas can still be changed, e.g. the mentioned assembly line, but the arrangement of areas in the factory is fixed. The focus of consideration now lies on the connection of these factory areas through production logistics processes, in other words the logistics transmission.

Therefore, the second major difference lies in the extension of the considered topics (topics three to seven) apart from topic one and two in the logistics transmission. These topics can be seen as design variables for the planning of production logistics processes. The different variations of these design variables lead to changes throughout all gear-wheels of the logistics transmission (see figure 6). The changeability now lies in the gear-wheels of the logistics transmission and illustrates the variety of planning scenarios in production logistics.

3. Number of production variants illustratable
   Increasing production variants are a major reason for the need of new concepts in production and logistics. The Lean movement, lean production systems and recently Industry 4.0 have been introduced to cope with that development [19].
4. Walking and transport distances
   In a lean production system, among other things, short walking and transport distances are in the focus of eliminating waste in processes.
5. Utilized shop floor space
   With increasing production variants, production companies face the challenge of handling this task with mostly restricted availability of factory space.
6. Logistics equipment in use
   As mentioned in section 4.1, this learning factory offers a wide range of different logistics equipment. The key to (more) efficient production logistics processes is the adequate choice and application of equipment for the specific situation. Since every technology has its advantages and disadvantages, production logistics planners have the task of planning lean and intelligent processes with the right equipment, depending on the requirements.
7. Implemented logistics concept
   Closely connected and interlinked to the mentioned topics above is the implementation of the right logistics concept and vice versa. For instance, the use of Industry 4.0 technology enables new concepts for internal material flow, e.g. the injection principle [18].

5. Simulation game for intelligent production logistics

As a result of the new learning factory content for intelligent production logistics, an adequate simulation game was developed as a part of the research project Diverstiy.Impuls (16OH21019) to teach the respective content. This simulation game is still in the evaluation period, accompanied by further research to test the proclaimed contents (see section 5.2). As it is mentioned in section 3 and 4.2, production logistics planners face the challenge of coping with increasing requirements regarding the flexibility, transformation ability and efficiency of production logistics processes [5]. Therefore, production logistics planners, mainly responsible for tactical and operational planning activities, are the focus group of this simulation game [20, 21].

5.1. Learning content

The main educational objective of this simulation game is to teach production logistics planners what Lean and Industry 4.0 means in the context of production logistics, which planning principles and methods exist and how they can use them to plan lean and intelligent production logistics processes with the application of Industry 4.0 technologies. Thus, the learning content is based on the analogy of the logistics transmission (see section 2.2), extended by the topics explained in section 4.2, which can be seen as design variables in the simulation game.

In general, the simulation game has several rounds. The trainer puts e.g. the focus on dealing with increasing production variants and therefore raises the number of production variants in every round. The participants then have to deal with this scenario and design the adequate production logistics processes. Each design variable offers them different options which they can use to create a proposed solution. The different technologies available in the learning factory for intelligent production logistics are thereby one major control lever. This way, the participants learn the adequate application of Industry 4.0 technology as a main design variable to handle the planning task, as well as the influence of the introduction of Industry 4.0 technology on other design variables. Figure 7 is an example how the proposed solutions are assessed after each round of the simulation game in all gear-wheels of the logistics transmission. In other words, among other things, it is assessed how the application of Industry 4.0 technology affects the designed production logistics processes. The assessment after each round is combined with an extensive debriefing session, where the trainer explains in detail the advantages and disadvantages of the proposed solution.

design variables	gear-wheel 1	gear-wheel 2	gear-wheel 3	round
cycle time	$75\ \frac{sec}{1}$	$30\ \frac{min}{1}$	$1\ \frac{h}{1}$	round of simulation game #1
size of carrier	Small load carrier	Small + large load carrier	Large load carrier	
# production variants	4	8	20	
utilized space	20 m²	80 m²	160 m²	
logistics equipment	flow racks	transport robot	handcart	
logistics concept	pick-by-light	taxi system	multi-step picking	
transport distances	10 m	170 m	75 m	

Figure 7: Assessment of proposed design solution

5.2. Evaluation concept

Since the concepts for the learning factory and simulation game for intelligent production logistics are in the starting phase, different methods are used to evaluate the success of the simulation game. The basic concept for the content of the new simulation game is based on findings obtained through literature research. To secure the learning success of the game, participants fill out questionnaires before and after the simulation game. In addition to that, the results of the planning tasks (see figure 7) from the different simulation rounds are also taken into account. As mentioned in section 5, this simulation game is still in the evaluation phase. Therefore, a survey is going to evaluate the specific problems of logistics planners in the field of intelligent production logistics. The findings of this survey will help to further improve and adjust the content of this simulation game.

6. Conclusion

The current developments regarding Industry 4.0 in the area of production logistics have shown the necessity to extend the content of the Lean learning factory (see section 3). It is recognized that the application of technologies opens new possibilities and design principles for production logistics processes. The concept of the novel learning factory for intelligent production logistics takes up the impact of Industry 4.0 on technology, organization and the design of production logistics processes and sets out to address these aspects in training for planners of production logistics processes.

During the mentioned starting phase of the learning factory and the new simulation game, it is necessary to evaluate the mentioned content and didactic approach. For a continuous improvement of the simulation game, a permanent feedback and evaluation tool will be implemented.

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